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Identification and Management of Summer Frost-prone Sites in the Cariboo Forest Region

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Identification and Management of Summer Frost-prone Sites in the Cariboo Forest Region

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FOREWORD

In recent years, foresters in the Interior of British Columbia have become increasingly aware that summer frosts can significantly affect the survival and growth of young forest plantations. As a result, they have requested guidelines for identifying frost-prone sites and for developing management practices to minimize the impacts of summer frosts. FRDA project 3.65 was initiated to meet these requests.

This is the second report prepared under FRDA project 3.65. The first report, prepared by R.J. Stathers and released in 1989 (*Summer Frost in Young Forest Plantations*, FRDA Report 073), summarizes the causes of summer frost and its impacts on young tree seedlings. The second report, presented here, is based on the principles outlined in the first report. It provides a means for assessing site-specific frost hazards in the Cariboo Forest Region and summarizes some management options for reducing the impacts of summer frost.

This report includes both a main text and a field guide. The field guide is contained in the back pocket and includes reference tables which can be inserted into a standard field notebook. The field guide is designed only as a field reference and should not be used without familiarity with the contents of the main report.

This report is a first approximation and will probably be updated as additional information on the occurrence of summer frost and its impacts on tree seedlings becomes available. The authors would greatly appreciate receiving any comments or suggestions for improvements to this guide.

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FIELD GUIDE INSERT

A Field Guide for Identifying Summer Frost-prone Sites in the Cariboo Forest Region
(See envelope inside back cover.)

1 INTRODUCTION

Summer frosts[1] can be a major cause of impaired growth and high mortality in conifer seedling plantations throughout the Cariboo Forest Region of central British Columbia. Temperatures colder than -4°C occur frequently on many sites during the summer months. These low temperatures can cause sublethal tissue damage and even mortality, depending on the tree species. Susceptibility of tree seedlings to damaging pathogens may also be initiated by frost injury (Reich and van der Kamp 1989). Frost damage symptoms have been observed in most biogeoclimatic subzones of the Cariboo Forest Region, and in some areas frost has been a major cause of plantation failure.

Long-term air temperature measurements from the Atmospheric Environment Service (AES) climate station network in the Cariboo Forest Region (Appendix 1) indicate that frosts can occur during the summer months in nearly all biogeoclimatic subzones of the region. Since these temperatures are measured at a height of 1.2 m above the ground surface, they underestimate the number and severity of frosts at the height of tree seedlings. Figure 1 shows that summer frosts can occur very frequently at seedling height in cutblocks in the Cariboo Region.

The frequency and severity of summer frost vary considerably among different sites within the Cariboo Region. The incidence of summer frost varies not only in different biogeoclimatic subzones, but also at a much smaller scale, such as in different microsites within a cutblock. An understanding of the factors that affect the occurrence of summer frost over the landscape makes it possible to predict which cutblocks, or areas within cutblocks, are most likely to experience summer frost. An assessment of frost risk at a site can then be used to select appropriate reforestation strategies to minimize the damaging effects of frost.

The purpose of this guide is to provide a framework for management of frost-prone sites in the Cariboo Forest Region. The location of the Cariboo Forest Region and the distribution of biogeoclimatic subzones within the region are shown on Figure 2. The guide reviews factors that affect the occurrence of summer frost and provides a simple method for rating the risk of summer frost for tree seedlings on recently planted sites in the region. It also briefly summarizes silvicultural options for reducing frost damage to tree seedlings and describes some symptoms of frost damage in conifer seedlings. The frost hazard ratings and interpretations are based on: 1) a network of recording minimum thermometers located on a wide range of sites in nine biogeoclimatic units; 2) remote thermal imagery; 3) Atmospheric Environment Service climate data records; and 4) observations of seedling frost damage throughout the region.

This guide is a **first approximation** and will be subject to change as more information about frost frequency and severity is obtained from the Cariboo Forest Region. The user of this guide is cautioned that the interpretations and guidelines presented here consider only frost effects and not the many other factors that also influence seedling performance.

2 FACTORS AFFECTING SUMMER FROST OCCURRENCE

Two different processes cause frost and thereby affect its occurrence throughout the landscape. *Radiation frosts* usually occur on calm, clear nights when the ground surface cools below 0°C as heat stored in the soil and air near the ground surface is radiated toward the atmosphere. *Local advection frosts* occur when cold air flows downhill and is concentrated in low-lying areas. A summary of factors affecting frost occurrence is outlined in Table 1. Additional information can be found in Stathers (1989).

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[1] Summer frost is defined, for purposes of this guide, as frost that occurs between the time when crop tree buds burst in the spring and their stems harden-off again in the late summer or fall.

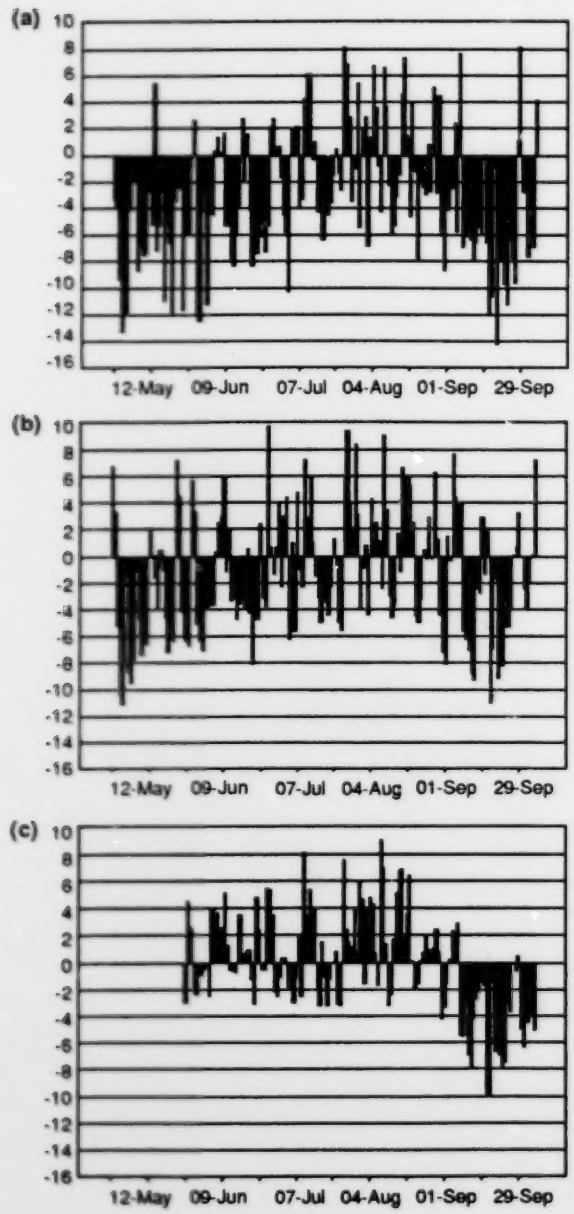
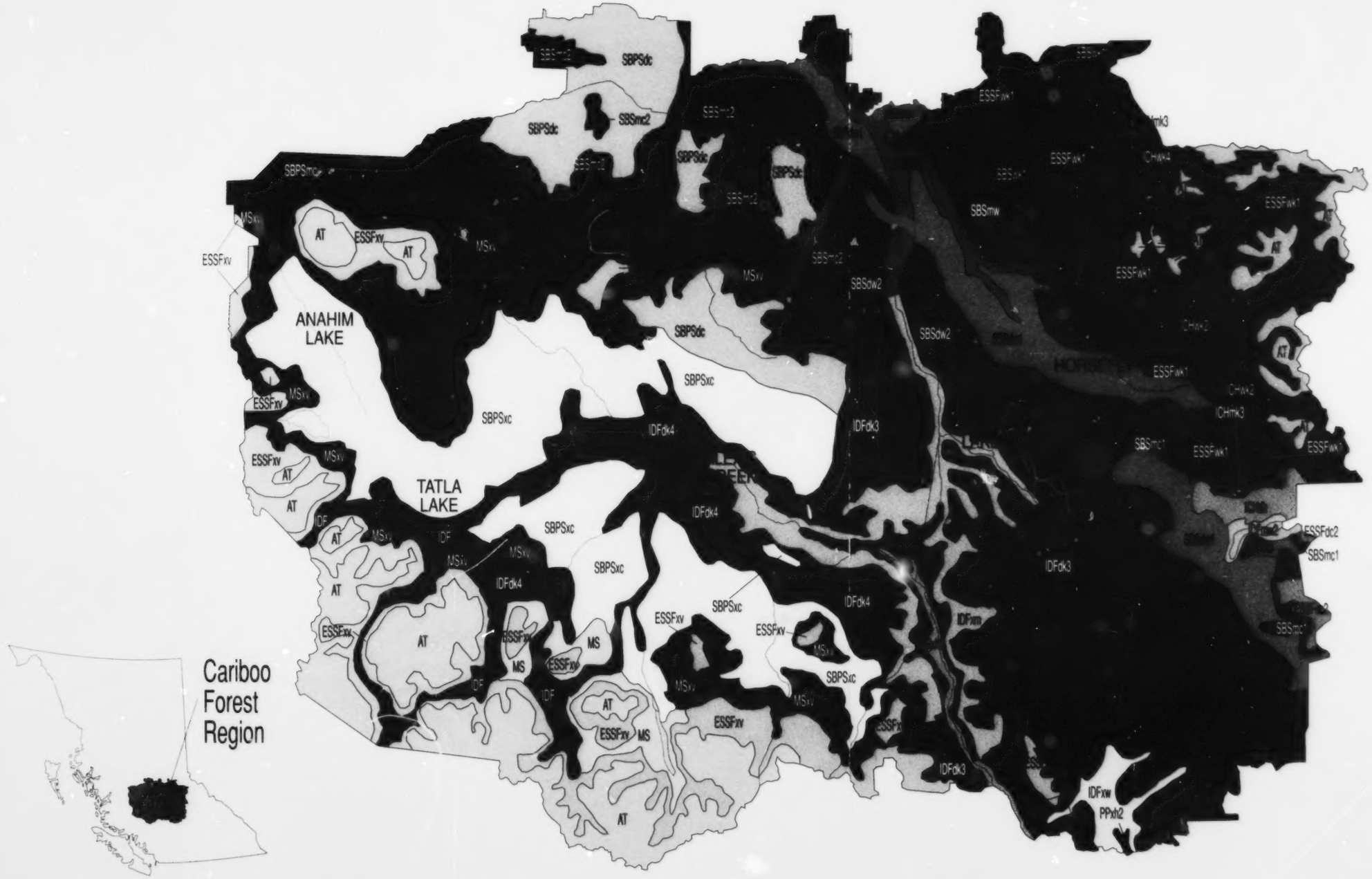


FIGURE 1. Minimum daily air temperatures measured during 1988 at a height of 15 cm above the ground surface in clearcuts in the (a) MSxc, (b) IDFdk3, and (c) ICHmk3.

Biogeoclimatic Units Of The Cariboo Forest Region



Legend

- AT: Alpine Tundra Zone

- BG: Bunchgrass Zone
  - xh3: Fraser Very Dry Hot
  - xw2: Alkali Very Dry Warm
- CWH: Coastal Western Hemlock Zone
  - ds1: Southern Dry Submaritime
- ESSF: Engelmann Spruce Subalpine Fir Zone
  - dc2: Thompson Dry Cold
  - wk1: Cariboo Wet Cool (includes ESSFwc3 - Cariboo Wet Cold - at elevations above 1500 m)
  - xv: Very Dry Very Cold
- ICH: Interior Cedar Hemlock Zone
  - dk: Dry Cool Interior Cedar Hemlock
  - mk3: Horsefly Moist Cool
  - wk2: Quesnel Wet Cool
  - wk4: Cariboo Wet Cool
- IDF: Interior Douglas-fir Zone
  - undifferentiated
  - dk3: Fraser Dry Cool
  - dk4: Chilcotin Dry Cool
  - mw2: Thompson Moist Warm
  - xm: Very Dry Mild
  - xw: Very Dry Warm
- MS: Montane Spruce Zone
  - undifferentiated
  - xk: Very Dry Cool
  - xv: Very Dry Very Cold
- PP: Ponderosa Pine Zone
  - xh2: Thompson Very Dry Hot
- SBPS: Sub-Boreal Pine Spruce Zone
  - dc: Dry Cold
  - mc: Moist Cold
  - mk: Moist Cool
  - xc: Very Dry Cold
- SBS: Sub-Boreal Spruce Zone
  - dw1: Horsefly Dry Warm
  - dw2: Blackwater Dry Warm
  - mc1: Moffat Moist Cold
  - mc2: Babine Moist Cold
  - mh: Moist Hot
  - mw: Moist Warm
  - wk1: Willow Wet Cool

FIGURE 2. Biogeoclimatic units and location of the Cariboo Forest Region.

TABLE 1. Atmospheric, site, ground cover, and soil factors that influence frost occurrence

Category	Factor	Effect on frost occurrence
Atmosphere	Air temperature	– Colder air requires less radiative heat loss to cool to the freezing point. – Cold air is denser than warm air, so it flows downhill and ponds in low areas.
	Cloud cover	– Clouds absorb longwave radiation and radiate it back toward the ground surface, thereby reducing the rate at which the ground surface and atmosphere cool at night.
	Wind speed	– Wind mixes the radiatively cooled air near the ground with warmer overlying air.
Site	Elevation	– Higher elevation sites are colder than lower elevation sites and radiatively cool more rapidly at night.
	Slope position	– Slope position affects the size of potential cold air source and receiving areas.
	Slope angle	– Slope angle affects the rate of cold air drainage and the amount of air mixing.
	Topography	– Topography affects cold air dispersion and accumulation. Convex slopes tend to be much less frost-prone than gullies, concave slopes, or flat areas where cold air either accumulates or drains slowly.
	Latitude	– Latitude affects the number of nighttime hours when the ground surface can radiatively cool, particularly in the early and late summer.
Vegetation Cover	Height & density	– Taller and denser vegetation canopies reduce radiative heat loss from the ground surface and thereby the rate of ground surface cooling at night.
	Species	– Vegetation cover having broad, flat leaves reduces radiative heat loss more than canopy covers having thinner, vertically oriented leaves.
Soil	Composition	– Soil texture, organic matter and water content, and bulk density affect the storage and release of heat in soil and thus the temperature of the ground surface at night.
	Surface material	– Organic surfaces have a lower capacity to store heat than do mineral surfaces and, as a result, cool to lower temperatures under the same conditions.

2.1 Atmospheric Conditions

Atmospheric conditions (air temperature, humidity, cloud cover and windspeed) largely determine whether summer frost will occur by affecting the rate at which the ground surface radiates heat toward the atmosphere. On cloudy nights, water vapour in the atmosphere absorbs most of the longwave radiation emitted by the ground surface. This causes both the atmosphere and ground surface to cool relatively slowly. In contrast, on clear nights when there is less water vapour in the atmosphere, more of the longwave radiation emitted from the ground surface is transmitted towards outer space. This causes the atmosphere to cool more rapidly, which in turn causes the ground surface to radiatively cool more rapidly.

The humidity of the atmosphere also affects how rapidly the air temperature drops as it loses heat at night. Humid air has a higher dewpoint temperature and contains much more latent heat (heat that is evolved as the water vapour in the air condenses and freezes on the ground surface) than dry air. As a result, areas with drier climates like the IDF zone tend to be more frost-prone than more humid areas like the ICH zone.

The density of air increases as it cools, causing it to settle near the ground surface and to flow downhill into lower-lying areas. Downslope cold air flow, or katabatic flow, has an important effect on the distribution of frost-prone sites, since cold air is dispersed from higher areas and concentrated in low-lying areas throughout the landscape. Sloping sites where cold air drainage occurs are therefore much less frost-prone than level or lower slope sites where cold air collects and continues to cool.

Under calm nighttime conditions, the air temperature at seedling height is usually many degrees C cooler than the air a few metres above the surface. This leads to the development of an air temperature inversion above the ground surface. Under windy conditions, the cold air generated near the ground surface is rapidly mixed with the warmer overlying air and the risk of frost is considerably reduced.

2.2 Site Factors

The risk of summer frost generally increases with elevation because the rate of radiative heat loss increases as the thickness of the colder overlying atmosphere decreases. Air temperatures are also typically lower at high elevation sites, so less radiative cooling is required to reach freezing temperatures. At elevations above 1300 m, the risk of radiation frost increases significantly in the Cariboo Region, particularly in the drier western half of the region where the humidity is often low.

Topography plays a very important role in redistributing cold air, as shown on the thermal image in Figure 3. Cold air settles at the ground surface and flows downhill into lower-lying areas, where it collects and forms frost pockets. Obstructions that impede this cold air flow can form small, localized frost pockets. Exposed, windy ridges and upper or mid-slope positions where cold air is able to drain away will usually have a much lower risk of summer frost than lower slope positions where cold air collects. They also have a lower risk of frost than level areas where cold air does not drain from the site. Figure 4 shows minimum air temperatures measured in different mesoslope positions along a transect in the SBSdw2 (Dry, Warm Sub-Boreal Spruce subzone, Blackwater variant).

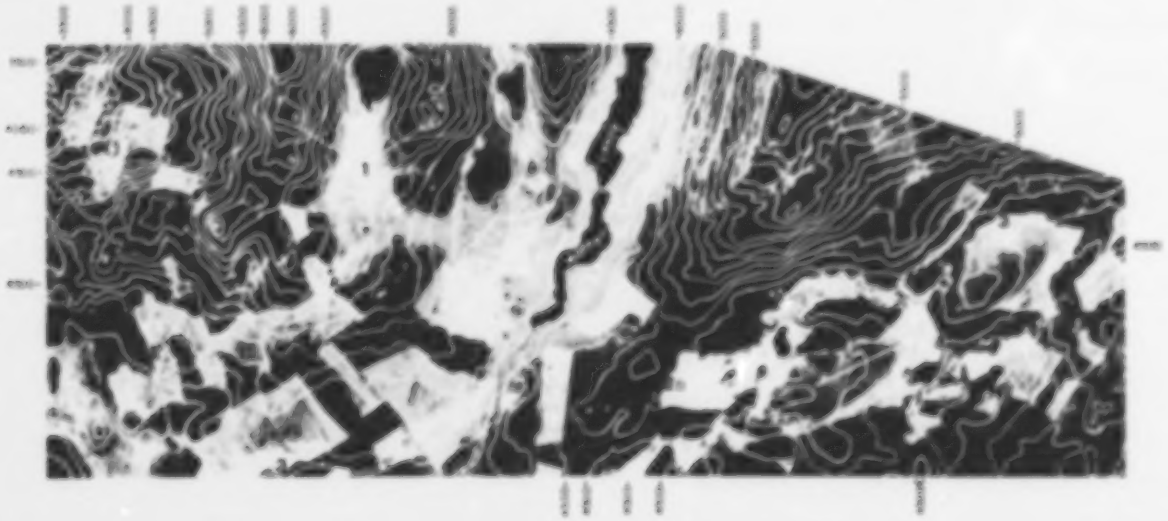


FIGURE 3. Thermal image of the area surrounding the Moffat Lakes (ESSFwk) showing (1) cold air redistribution from shedding to receiving positions, (2) steeper slopes (2a) that are warmer than flatter areas (2b), and (3) cold air ponded behind cutblock boundaries that act as air flow barriers. Tones represent 2°C temperature intervals from less than -6°C (whitest) to greater than +6°C (darkest).

On the flat and gently rolling plateau, typical of much of the central Cariboo Forest Region, cold air that is generated at the ground surface is unable to drain away rapidly into lower-lying gullies and valleys. As a result, this terrain can be subject to a relatively high radiation frost frequency. Small knolls that project only a few metres above the level terrain can have a much lower frost hazard than the adjacent hollows or lower areas where cold air ponds. Similar principles apply at very small scales on this level terrain. Small hollows and depressions, with changes in relief of no more than a few decimetres, collect cold air and can increase the risk of frost damage in individual planting microsites.

The size of the airshed above a site can also affect the frequency and severity of frost. The larger and higher the airshed from which cold air drains onto a site, the greater the potential frost hazard becomes. Valley bottoms beneath glaciers and flat benches beneath long sideslopes are particularly frost-prone.

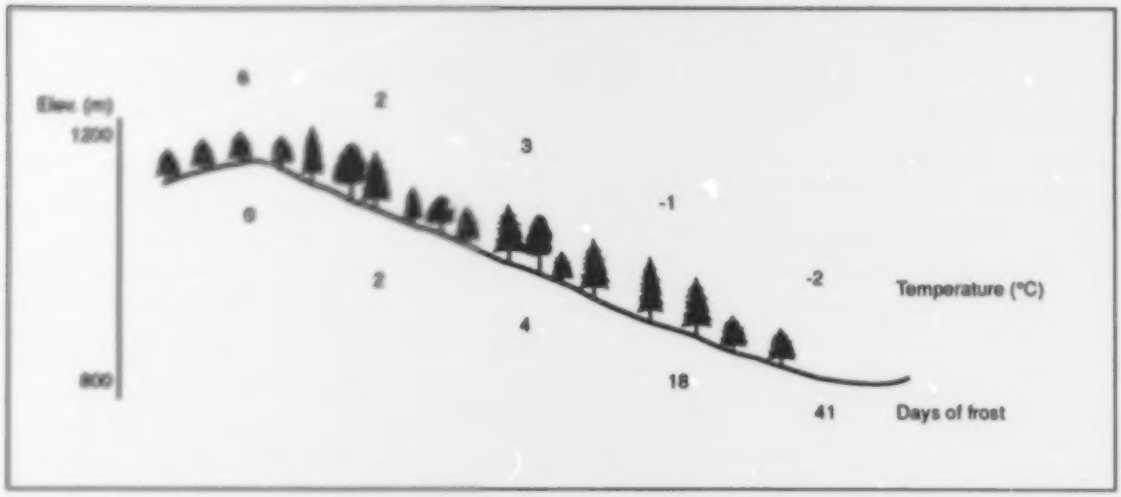


FIGURE 4. Minimum overnight (June 12, 1988) air temperatures and number of days with frost between June 1 and August 30, 1988, on a mesoslope transect in the SBSdw2 near Pantage Lake, B.C.

Slope gradient affects the rate at which cold air flows downhill. On slopes steeper than about 15%, the cold air generated at the ground surface drains rapidly and causes turbulence that mixes the warmer overlying air with the colder air generated near the surface. In general, the steeper the slope, the more rapid the downslope air flow becomes.

Sloping surfaces also have a lower frost risk because they have a proportionately smaller view of the cold night sky which reduces the rate of surface radiative cooling. South-facing slopes may have a slightly lower frost risk than north-facing slopes because of increased daytime soil heat storage and shorter nights. This effect is less pronounced in the summer than in the spring or fall when aspect has a greater effect on solar irradiance. It is most pronounced on sunny days when soil heat storage is large. Severe frosts are also more likely to occur in the spring and fall when the longer nights allow more time for radiative cooling to occur.

2.3 Vegetation and Slash Cover

Vegetation and slash cover reduce the frost hazard for seedlings by blocking out portions of the cold night sky and thus reducing the rate of radiative heat loss from the ground surface. However, they can also reduce air mixing near the ground, decrease daytime soil heat storage by shading the surface, and restrict cold air drainage, thereby increasing the potential risk of frost at night.

The effect of vegetation and slash cover on frost risk depends on the characteristics of the vegetation or slash canopy. Tall, dense shrub or herbaceous canopies that overtop seedlings and cover more than about 50% of the ground surface considerably reduce the frost hazard for seedlings because the effective radiative exchange surface where the coldest temperatures occur is near the top of the vegetation, well above the seedlings. Shorter grass canopies do not provide as effective thermal cover because radiative cooling occurs near the top of the grass, at the level of the seedling foliage where frost damage is likely to occur.

Seedlings planted adjacent to large stumps or logs can also benefit from the reduced sky view factor and the heat that is stored in the woody material. Raised mineral soil near large or overturned stumps are usually warmer microsites. Vegetation and logging slash piles can block the downslope flow of cold air

and increase the frost hazard on the upslope side of the barrier. At a larger scale, cold air can also pond on the upslope sides of timber leave-strips as shown in the thermal image in Figure 4.

2.4 Soils

Heat stored in the soil during the day is conducted back toward the ground surface and radiated toward the atmosphere at night. Silvicultural treatments that increase daytime heat storage in the soil (e.g., by removing surface organic layers and vegetation cover) allow ground surface temperatures to remain higher at night.

Organic surface horizons do not store and transmit heat as effectively as mineral soils. Frost is therefore much more likely to occur above an organic surface than above a mineral surface. Moist soils are also better able to buffer changes in temperature than are dry soils, so frost is much more likely to occur when the soil surface is dry than when it is wet.

3 FROST HAZARD ASSESSMENTS IN THE CARIBOO FOREST REGION

3.1 Definition of Frost Hazard Classes

The approach to frost hazard assessments in this guide is to assign one of five frost hazard classes to a site based on readily identified features of the site. These hazard classes, which range from very low to very high, are defined in Table 2. The hazard classes are defined by an expected frost frequency and by the degree of frost damage anticipated on clearcut sites in young plantations of lodgepole pine (*Pinus contorta*), interior spruce (*Picea engelmannii*, *P. glauca*, and their hybrid), and Douglas-fir (*Pseudotsuga menziesii*).

TABLE 2. Definition of frost hazard classes for the Cariboo Forest Region

<table>
<tr><th rowspan="3">Summer frost hazard class
expected incidence</th><th colspan="6">Expected damage and mortality</th></tr>
<tr><th colspan="2">Douglas-fir</th><th colspan="2">Interior spruce</th><th colspan="2">Lodgepole pine</th></tr>
<tr><th>Damage</th><th>Mortality</th><th>Damage</th><th>Mortality</th><th>Damage</th><th>Mortality</th></tr>
<tr><td>Very Low VL
0 in 10 years <-4°C
0 in 10 years <-8°C</td><td rowspan="2">None</td><td rowspan="2">None</td><td rowspan="3">None</td><td rowspan="3">None</td><td rowspan="5">None</td><td rowspan="5">None</td></tr>
<tr><td>Low L
1-2 in 10 years <-4°C
0 in 10 years <-8°C</td><td rowspan="2">Moderate</td><td rowspan="2">Limited</td></tr>
<tr><td>Medium M
3-6 in 10 years <-4°C
1-2 in 10 years <-8°C</td><td rowspan="4">Severe</td><td rowspan="4">Extensive</td><td>Moderate</td><td rowspan="2">Limited</td></tr>
<tr><td>High H
7-10 in 10 years <-4°C
3-5 in 10 years <-8°C</td><td rowspan="2">Severe</td><td>Moderate</td><td rowspan="2">Limited</td></tr>
<tr><td>Very High VH
10 in 10 years <-4°C
>5 in 10 years <-8°C</td><td>Extensive</td><td>Severe</td></tr>
</table>

The damage classes used to define frost hazard class in Table 2 are:

None: little or no apparent damage to foliage is expected;

Moderate: damage to shoot tips or buds and impaired shoot growth is expected;

Severe: extensive tissue death and loss of foliage is expected.

The mortality classes used to define frost hazard class in Table 2 are:

None: little or no mortality is expected within the area rated;

Limited: small amounts of mortality (often in isolated, low-lying microsites) are expected;

Extensive: widespread mortality is expected in the area rated, and stocking levels will likely be significantly reduced.

Each frost hazard class has a different combination of damage and mortality hazards for these three species. Low hazard class sites are those where Douglas-fir, a frost-sensitive species, is at risk but spruce and pine are not. Medium hazard class sites are those where Douglas-fir and interior spruce are at risk, but lodgepole pine is not. All three species, especially Douglas-fir, are at risk on High hazard class sites. These three species represent the range of frost sensitivities among tree species in the Cariboo Forest Region.

The degree of frost damage and mortality that defines each hazard class can be anticipated in 1 or more years during the establishment of a plantation. However, this degree of damage may not occur every year, because of annual variation in the frequency and severity of frost.

The frost hazard classes defined in Table 2 are based on several sources of information. These include extensive observations of plantation frost damage and short-term frost occurrence data from approximately 85 locations in the Cariboo Forest Region. This information has been used to derive the estimates of the probability of minimum air temperatures at seedling height dropping below either -4 or -8°C during the growing season. Observations of frost damage in young plantations throughout the region suggest that Douglas-fir will occasionally suffer damage and isolated mortality on Low hazard class sites. Severe damage and greater mortality has been noted on Medium hazard class sites. Similarly, interior spruce will occasionally suffer damage and isolated mortality in the Medium hazard class areas and extensive damage and growth reductions in the High hazard class areas. It generally cannot be regenerated on Very High hazard class areas. Lodgepole pine is comparatively frost tolerant and has not been noted to suffer extensive damage and mortality except on Very High hazard class sites. It will survive and grow even on some of these sites. Western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) appear to have a frost tolerance similar to that of Douglas-fir. Subalpine fir (*Abies lasiocarpa*) foliage apparently has a frost tolerance slightly greater than that of interior spruce, though its buds might be more sensitive to frost.

Table 2 can be consulted for the silvicultural implications of planting lodgepole pine, interior spruce, or Douglas-fir; that is, for assessing species-specific frost hazards. For example, summer frost does not affect regeneration of the respective species in its "no damage, no mortality" area of the table, but definitely affects regeneration success in its "severe damage, extensive mortality" area. The "moderate damage, limited mortality" areas of the table have a less definitive summer frost hazard, where the potential frost damage or mortality hazards must be weighed against the need or desire to regenerate a certain species. The hazard classes in these intermediate areas are often much harder to identify than those in either of the other areas because of the annual variations of frost occurrence and the complexity of additional factors that affect frost occurrence and severity in these areas.

The relationship between the frequency and severity of summer frosts and the resulting degree of damage and mortality that each species is likely to exhibit is not simple. The summer frost tolerance of conifer seedlings appears to be both genetically and environmentally controlled. For example, there may be considerable differences in frost tolerance within provenances or seedlots of the same species. Physiologically active seedlings, such as those supplied with optimum nutrients and moisture, are generally more susceptible to frost than seedlings with reduced activity and vigour. It also appears that if seedlings are frequently subjected to light frosts during the growing season, they may become

conditioned to withstand the harder frosts that might occur in late summer without showing symptoms of damage.

3.2 Determining the Summer Frost Hazard Class at a Site

The summer frost hazard class of a site is assessed in this guide from the regional climate (biogeoclimatic unit), terrain features, and topographic setting of the site. The frost hazard classes are intended to be applied at the scale of a typical cutblock (80 ha or less) or portion of a cutblock. Frost hazard assessments should be made only for sites with relatively uniform mesoslope position and slope gradient. If a proposed or existing cutblock includes more than one mesoslope position or includes both steep and gentle slopes, the area should be stratified into homogeneous units, and separate frost hazard class assessments should be made for each unit.

The approach used in this guide to identify the frost hazard class at a site involves two steps. In the first (Section 3.2.1), a preliminary frost hazard class rating for a site is determined from Table 3. This preliminary rating is based on regional climate (biogeoclimatic unit), position of the site on the slope, and steepness of the slope. These three factors account for a large proportion of the variation among sites in their risk of summer frost. For example, the mean frequency of summer frosts in 1988 increased substantially as the hazard class ratings increased from Very Low to Very High among several sites (Figure 5). However, other site characteristics may also significantly affect the risk of summer frost at a site.

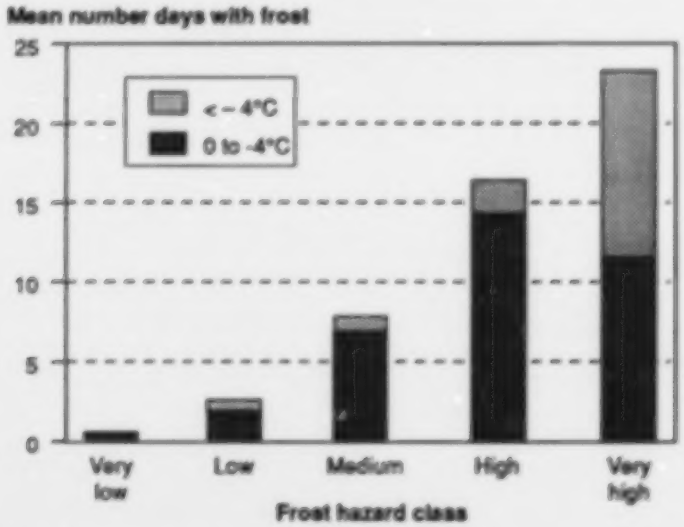


FIGURE 5. Average number of days of frost (at the 15 cm height) in frost hazard classes recorded in 35 cutover sites in the Cariboo Forest Region between June 1 and August 31, 1988. (Sites were located in the ICHmk3, SBSdw2, IDFdk3, and MSxc).

In the second step (Section 3.2.2), the preliminary rating for a site may be adjusted according to certain site-specific characteristics that increase or decrease the hazard. These characteristics include terrain features of the site and its topographic setting, as well as certain features of the site that can be modified by forestry practices. **Both steps 1 and 2 should be completed to achieve the best frost hazard class rating for the site.**

3.2.1 Preliminary frost hazard class rating

The preliminary hazard class rating for a site is determined from Table 3. Descriptions of the site features used in this table are outlined in the following sections.

Biogeoclimatic subzones and variants

Regional climate and physiography have a major influence on the frequency and severity of summer frost. Biogeoclimatic subzones and variants are areas of relatively uniform macroclimate and physiography and thus provide useful stratification of the landscape for frost hazard assessments.

The effects of regional climate and physiography on summer frost are complex. They are related not only to regional mean temperature and elevation, but also to typical nighttime atmospheric humidity and cloud cover. For assessing frost hazard, biogeoclimatic subzones and variants of the Cariboo Forest Region have been placed in eight groups. The regional climates and physiographies within each of these groups are considered to have similar net effects on summer frost frequency and severity.

Group 1 biogeoclimatic units (BGxh3, BGxw2, IDFxw, PPxh2) include the relatively hot, dry subzones and variants that occur primarily in low elevation valleys. Severe summer frosts are infrequent because of low elevations, moderate to steep slopes, and large daytime soil heat storage.

Group 2 biogeoclimatic units (IDFdk1, IDFmw2, IDFxm, SBSmh) also include low elevation, warm subzones that occur primarily in valleys, but at higher latitudes than those of Group 1. This group includes the IDFxm in the Fraser River Valley, but not in the Chilcotin and Chilanko river valleys west of Hanceville.

Group 3 biogeoclimatic units (ICHdk, ICHmk3, ICHmw3, ICHwk2, ICHwk4, SBSdw1) include low to moderate elevation subzones of the Fraser Plateau and Quesnel Highlands where radiative cooling is reduced by relatively high atmospheric humidity and cloud cover. Severe summer frosts occur primarily at the base of slopes where cold air collects. Upslope areas and slopes steeper than about 15% experience little summer frost.

Group 4 biogeoclimatic units (IDFdk3, IDFxm, SBSdw2, SBSmw) also occur at low to moderate elevations, but are more frost-prone than Group 3 subzones, since their drier climates result in more rapid nighttime radiative cooling. The level to gently rolling topography typical of many parts of this group results in significant microscale differences in frost hazard.

Group 5 biogeoclimatic units (IDFdk4) occur at low to moderate elevations, but experience more frequent and severe summer frosts than Group 4 units because of a drier climate and more rapid nighttime radiative cooling. This group includes the most frost-prone areas, where Douglas-fir forests are common in the Cariboo Forest Region.

Group 6 biogeoclimatic units (MSxk, SBPSdc, SBPSmc, SBPSmk, SBSmc1, SBSmc2) have a high frequency of summer frost because of their moderate to high elevations and climates with intermediate to dry moisture regimes. The SBPS units in this group have predominantly level to gently rolling terrain with significant microscale frost hazard differences.

Group 7 biogeoclimatic units (ESSFdc2, ESSFwk1, SBPSxc, SBSwk1) experience frequent summer frosts because of their high elevations or, if elevations are moderate, their very dry climates.

Group 8 biogeoclimatic units (ESSFwc3, ESSFxv, MSxv) include the most summer frost-prone forested areas of the Cariboo Forest Region. Frequent severe summer frosts result from high elevations and very dry climates.

The biogeoclimatic classification for a site can be determined from biogeoclimatic unit maps available from the Forest Sciences Section, Cariboo Forest Region. A small scale, less detailed biogeoclimatic map of the Cariboo Forest Region is shown in Figure 2.

TABLE 3. Guide to preliminary frost hazard class ratings for clearcuts in the Cariboo Forest Region

Biogeoclimatic subzones/variants	Mesoslope position	Slope gradient	Frost hazard
Group 1: BGxh3,xw2 IDFxw PPxh2	Crest, Upper, Mid	> 5%	VL
	Lower	>15%	VL
		<15%	L
	Toe, Depression, Level	< 5%	L
Group 2: IDFdk1 IDFmw2 IDFxm (Fraser R.) SBSmh	Crest	> 5%	VL
	Upper, Mid	>15%	VL
		<15%	L
	Lower	all slopes	L
	Toe, Depression	< 5%	M
	Level	< 5%	L
Group 3: ICHdk ICHmk3 ICHmw3 ICHwk2,wk4 SBSdw1	Crest	> 5%	VL
	Upper, Mid	>15%	VL
		<15%	L
	Lower	>15%	L
		<15%	M
	Toe, Depression	< 5%	H
	Level	< 5%	L
Group 4: IDFdk3 IDFxm (Chilcotin) SBSdw2 SBSmw	Crest	> 5%	VL
	Upper	>15%	VL
		<15%	L
	Mid	>15%	L
		<15%	M
	Lower	>15%	L
		<15%	M
	Toe, Depression	< 5%	H
	Level	< 5%	M
Group 5: IDFdk4	Crest	> 5%	VL
	Upper	>15%	VL
		<15%	M
	Mid	>15%	L
		<15%	M
	Lower	>15%	L
		<15%	H
	Toe, Depression	< 5%	H
	Level	< 5%	M
Group 6: MSxk SBPSdc SBPSmc SBPSmk SRSmc1,mc2	Crest	> 5%	L
	Upper, Mid	>15%	L
		<15%	M
	Lower	>15%	M
		<15%	H
	Toe, Depression	< 5%	H
	Level	< 5%	M
Group 7: ESSFdc2 ESSFwk1 SBPSxc SBSwk1	Crest	> 5%	L
	Upper, Mid	>15%	M
		<15%	H
	Lower	>15%	M
		<15%	H
	Toe, Depression	< 5%	VH
	Level	< 5%	H
Group 8: ESSFwc3 ESSFxv MSxv	Crest	> 5%	M
	Upper, Mid	>15%	M
		<15%	H
	Lower	>15%	H
	Lower, Toe, Depression	<15%	VH
	Level	< 5%	VH

Mesoslope Position

Mesoslope position can be used to classify sites as to whether they are likely to shed or receive radiatively cooled air. Convex crest and upper slope positions and straight mid-slope positions are typically source areas that shed cold air, and they are less frost-prone than concave lower or toe slopes where cold air collects.

Mesoslope positions, as defined by Luttmerding *et al.* (1990) (Table 4) and used by the ecosystem classification program in British Columbia, also describe the position of sites within an air flow catchment area. That is, they describe the relative position of sites within the path of uninterrupted downslope air flow extending from the source areas at the top of a slope to the receiving areas at the bottom of a slope. The difference in elevation between the top and bottom of a mesoslope is generally between 3 and 300 m. Mesoslopes can vary in length from tens of metres to many kilometres. Two or more mesoslope sequences can be contained within one longer toposequence or macroslope (Figure 6).

TABLE 4. Characteristics of mesoslope positions

Crest positions are the generally convex hilltops and ridgetops that shed but do not receive cold air from above. Caution: On broad hilltops, slopes less than 5% that do not shed cold air to downslope sites should be considered level areas rather than crest positions.
Upper slope positions are generally convex areas just below the crest and generally within the upper third of the mesoslope. Slope grades are greater than 5%.
Mid-slope position is the area of a slope between the upper and lower mesoslope positions where the slope is neither convex nor concave, but rather generally straight. Mid-slope positions receive and shed cold air approximately equally.
Lower slope position is the area near the base of a hill where the slope is generally concave. It is an area of net accumulation of cold air.
Toe slope position is an area of slight or no slope grade at the base of hill. It is below and adjacent to a lower mesoslope position. It is an area of increased cold air accumulation.
Depressions are areas near the base of a mesoslope or in level terrain, which are concave in all directions and accumulate, but do not shed cold air.
Level areas are generally horizontal areas (<5% slope gradient) that neither shed nor receive cold air to or from other mesoslope positions. They are extensive on level plains and plateaus. Long mid- and upper slope positions with less than 5% slope grades should be treated as level areas.

To identify the mesoslope position of a site for frost hazard assessment, the user of this guide should imagine a thin blanket of cold air moving slowly downhill from hilltops and ridgecrests to lower-lying areas where it accumulates. As it moves downhill from one or several source areas, it may diverge around small hills which thus form part of another mesoslope sequence. The bottom of the mesoslope is the area where the cold air ponds, and where further downslope movement is very slow or nonexistent. Various microslope positions (generally at an elevational scale of less than 3 m) may occur within a single mesoslope position. The assessment of air flow patterns and the identification of mesoslopes can be greatly aided by the examination of aerial photographs and medium scale topographic maps.

The amount of verticle relief that distinguishes microslope from mesoslope sequences (generally about 3 m) is not constant. For example, on toe mesoslope positions, where cold air accumulates, small knolls need to rise more than 3 m before their upper slopes have frost hazards characteristic of upper mesoslope positions.

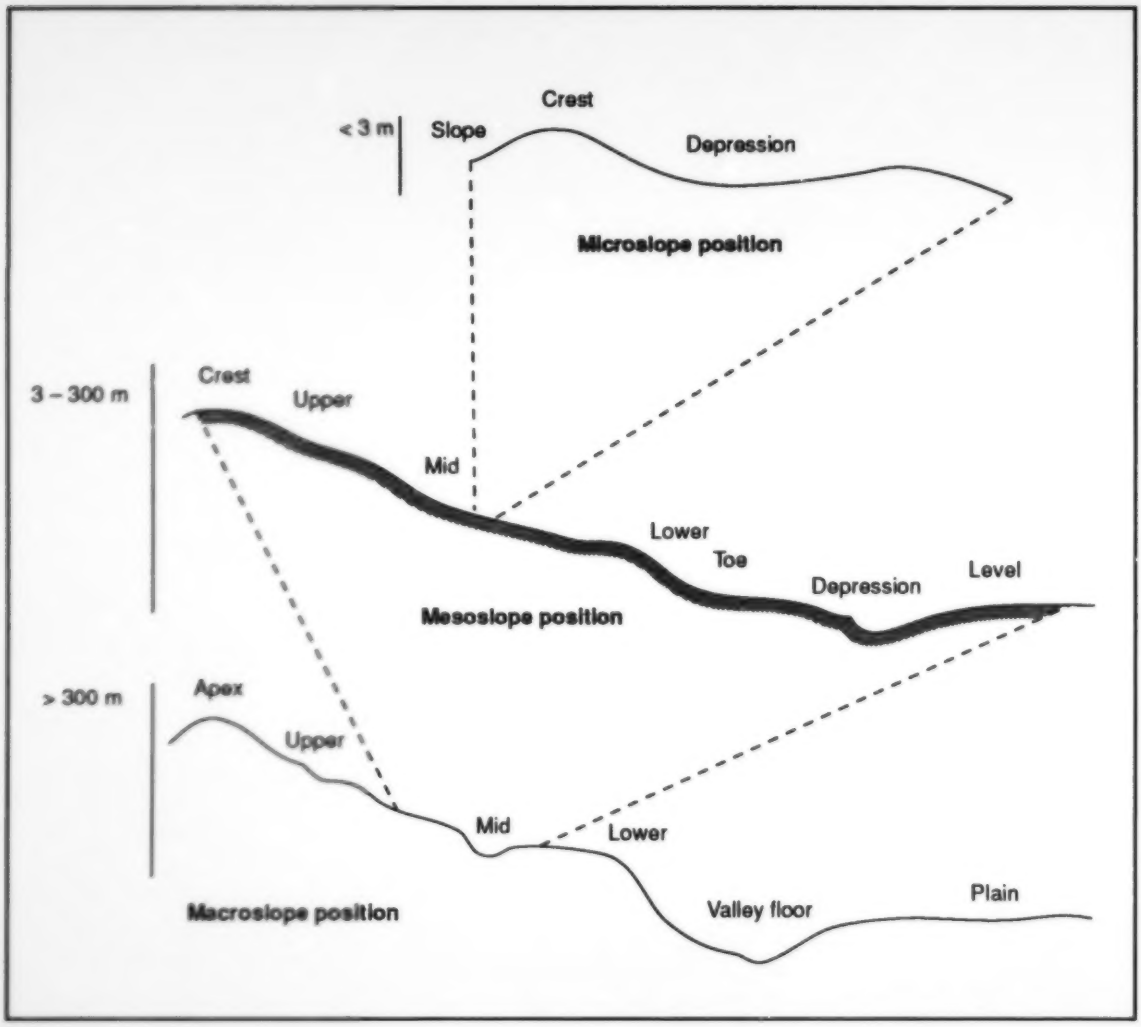


FIGURE 6. The location of mesoslope positions within a macroslope toposequence.

Slope Gradient

Slope gradient determines the rate of cold air movement through a site and the degree of mixing of cold surface air with the warmer overlying air (see Section 2.2). Cold air appears to readily disperse from sites where the slope gradient exceeds about 15%. That is, slope gradients greater than about 15% in this study had a lower frequency of frost than did gentler slopes.

Slope gradient should be measured between the highest and the lowest points of the site to be rated, excluding isolated raised knobs and depressions.

3.2.2 Modifying the preliminary hazard class rating based on additional site factors

Many atmospheric- and site-dependent factors interact to determine the hazard of plantation damage due to summer frost at a site. Biogeoclimatic unit, mesoslope position, and slope gradient integrate many of these factors and provide a useful initial approximation of frost hazard. However, for site-specific frost hazard assessments, a number of additional factors should also be considered.

How any additional site or atmospheric factor will affect frost occurrence at a site must be evaluated in the context of the other factors with which it interacts. No single factor should be considered in isolation. For purposes of detailed frost hazard assessment, it is generally best to consider as many factors as possible that could contribute to the overall frost hazard at a site, and then evaluate their combined effects on the overall hazard. Some of the more important additional site-specific factors that can increase or decrease the frost hazard at a site are described below.

1) Upslope Source Area. The presence of large upslope cold air source areas (generally extending more than 300 m vertically) that drain into a cutblock can increase the frequency and severity of summer frosts. Cutblocks on level to gently sloping terrain or in a confined valley bottom below these large source areas are particularly at risk. Lower valley slopes and valley bottoms in high relief mountainous terrain are examples where frost hazard may be increased by as much as one class due to a large upslope source area.

2) Impediments to Air Drainage. Impediments to cold air drainage through a cutblock can increase the frequency and severity of frosts on the upslope side of the impediment. Examples of impediments include standing timber on the downslope side of a cutblock and hummocks or low ridges within a cutblock. A timber boundary has the greatest effect on upslope frost hazard when it occurs on gentle to moderate slopes where downslope cold air movement is relatively slow. Frost hazard may be increased by as much as one class close to the timber edge. The effects of air drainage impediments can be seen at the microscale as well as at the mesoscale.

3) Cold Air Channels. Downslope cold air flow may be channeled or concentrated into certain areas by small topographic variations such as stream channels, gullies, hummocks, and small hollows. The frost hazard may be increased in these areas, especially if the slopes are gentle. On adjacent or intervening portions of the slope, frost hazard may be slightly decreased. This effect can be seen at the microscale as well as at the mesoscale. Aerial photographs and medium scale topographic maps can be helpful for detecting topographic features that channel or concentrate cold air flow.

4) Microtopography. Microtopographic depressions (Figure 6) within a cutblock may have a frost hazard rating one class higher than adjacent areas, especially on level or gently sloping terrain. Similarly, microtopographic crests, projecting 2-3 m above the normal surface of the site, may have a frost hazard rating one class lower than adjacent areas, especially on level plateau surfaces. On lower and toe slope positions, where cold air accumulates, 5 m of relief is often necessary to reduce frost hazard class by one.

5) Slope Aspect. North aspects have a slightly higher risk of summer frost than do other aspects (see Section 2.2).

6) Vegetation and Slash Cover. The risk of radiation frosts can be significantly decreased by a tall vegetation canopy that blocks 50% or more of a seedling's view of the night sky. For example, the frost hazard on a level slope position may be as much as one class less beneath a tree or tall shrub canopy than in an adjacent clearcut. (However, a tall vegetation canopy may have negative impacts on other aspects of a tree seedling's environment.) Abundant slash cover on a site may also reduce frost hazard, especially on microsites where the tree seedling's view of the night sky is blocked 50% or more by woody debris. Vegetation dominated by low grasses, such as pinegrass (*Calamagrostis rubescens*), may increase the frost hazard by one class, especially on level sites.

7) Mineral Soil Exposure. Hazards of radiation frost are often less on microsites with exposed mineral soil than on those covered by low vegetation or organic layers. However, frost hazard on a site prone to severe local advection frost will not be much reduced by mineral soil exposure. The

effect of mineral soil exposure on frost hazard is most pronounced on level and shedding slope positions.

In an assessment of frost hazard at a site, plantations on similar sites nearby should also be examined for signs of frost damage. Symptoms of frost damage (Appendix 2) are readily identifiable and often persist for many years.

3.3 Vegetation Indicators of Frost-prone Sites

Presence or absence of certain species, as well as vigour of the vegetation, may be used as indicators of frequent summer frosts.

The use of plant species as indicators of frost-prone sites requires information on the moisture and nutrient requirements of the species. Since frost-prone sites are also often wet or nutrient-poor sites, the response of a species to moisture and nutrient conditions should be known before frost indicator value is assessed. For example, the absence of a frost-sensitive species or group of species that is common on other sites with similar soil moisture and nutrient regimes may indicate that the site experiences frequent summer frosts.

Although much more information is needed on the frost indicator values of plant species, some examples can be given of vegetation that indicates frequent summer frosts in the Cariboo Forest Region.

In the Interior Cedar Hemlock Zone, a moist, lower slope site with loamy textured soils probably experiences frequent summer frosts if:

- hybrid white spruce and subalpine fir dominate the tree canopy and Douglas-fir, western redcedar, and western hemlock are absent even though they are common on upslope sites;
- black twinberry (*Lonicera involucrata*) is present and devil's club (*Oplopanax horridus*) is absent; and
- Indian hellebore (*Veratrum viride*) is common.

In the Interior Douglas-fir Zone, a moist, lower slope site with loamy textured soils probably experiences frequent summer frosts if:

- lodgepole pine is dominant and Douglas-fir is absent from a mature forest even though Douglas-fir dominates in the forest on upslope sites;
- glaucous willow (*Salix glauca*) and scrub birch (*Betula glandulosa*) are present;
- kinnikinnick (*Arctostaphylos uva-ursi*) and lichens are abundant; and
- feathermosses (*Pleurozium schreberi, Ptilium crista-castrensis*, and *Hylocomium splendens*) are absent or very poorly represented, and glow moss (*Aulacomnium palustre*), Dicranum mosses (*Dicranum* spp.) or juniper hair-cap moss (*Polytrichum juniperinum*) are abundant.

In the Sub-Boreal Spruce Zone, a moist, lower slope site with loamy textured soils probably experiences frequent summer frosts if:

- black spruce is present (does not apply to areas north of the Cariboo Region);
- pink spirea (*Spiraea douglasii*) is abundant; and
- dwarf scouring rush (*Equisetum scirpoides*) is abundant, while common horsetail (*E. arvense*) and wood horsetail (*E. sylvaticum*) are absent.

Plant species diversity and vigour are generally lower on frost-prone sites than on others that have comparable moisture and nutrient regimes. For example, low-growing forbs and grasses (other than pinegrass) and lichens (especially *Cladina* spp.) are often more prominent on frost-prone sites than would be expected for sites with similar moisture and nutrient regimes.

Historical evidence of frost can often be interpreted from tree frost ring analyses (Reich and van der Kamp 1989).

3.4 Sample Frost Hazard Class Assessments

Figure 7 portrays typical landscapes of the IDFdk3 and the ICHmk3 and shows some sample frost hazard class ratings as they would occur on these landscapes.

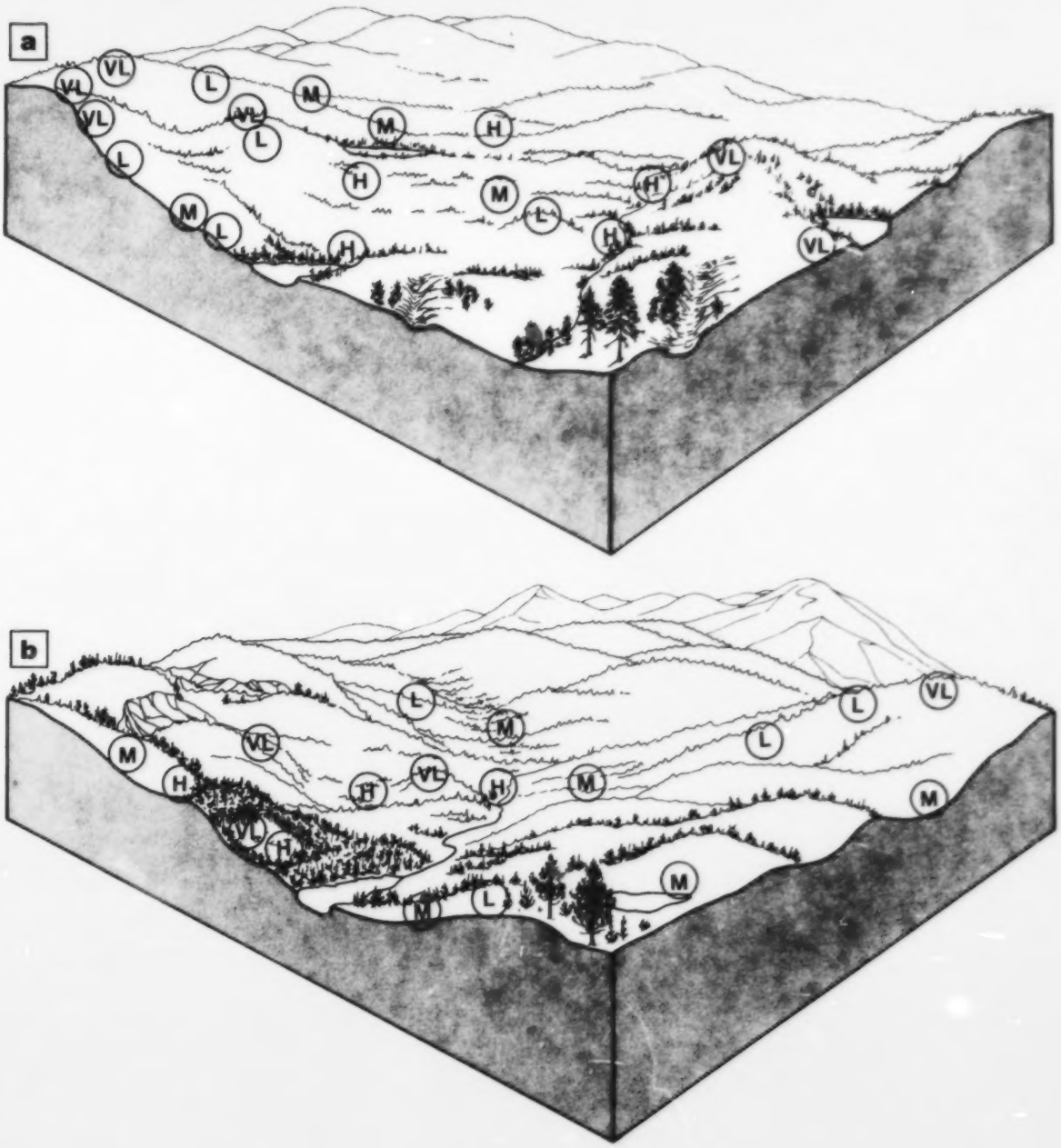


FIGURE 7. Sample frost hazard ratings on typical terrain in the (a) IDFdk3 and the (b) ICHmk3.

In the IDFdk3 (Figure 7a), High hazard class ratings occur at the toe of slopes and in depressions. Medium hazard class ratings occur on gentle mid-slopes, a gently sloping bench on a lower slope position (left foreground), and on a level plain. Low ratings occur on steep mid-slope positions, a short but steep lower slope position (left foreground), and a gentle upper slope position. Crests and steep upper slope positions have a Very Low rating.

In the ICHmk3 (Figure 7b), High hazards occur at the toe of slopes and on a gentle lower slope against a timber boundary (the potential hazard is increased because cold air drainage is impeded and there is no provision for outflow). Medium hazard class ratings are shown on gentle lower slopes. Low ratings occur on gentle upper and mid-slope positions; Very Low ratings occur on crests and steep slopes.

4 MANAGEMENT OF FROST-PRONE SITES

A number of silvicultural treatments can be used to improve regeneration success on frost-prone sites. The degree of success depends on the frost hazard class and the severity and frequency of frosts during the first few years of establishment. Because of the annual variation in summer weather conditions, success with certain treatments in years with average growing season weather conditions might not occur in adjacent cutblocks in other colder years.

It is important to learn how to recognize the frost hazard class, or range of frost hazard classes, that occur within a cutblock. Recognizing where potential frost problems exist and how severe they will be is the first step toward a solution of the problem. Various strategies can then be applied to achieve a high quality, free-growing plantation at lowest cost.

4.1 Site Preparation Treatments

A range of mechanical site preparation treatments may reduce the risk of frost damage on Low and Medium frost hazard sites. Trenches ripped to a depth of 30–50 cm with a ripper plow may reduce frost damage in dry climates (Adams and Black 1990; Black *et al.* 1990). The trenches increase heat transfer into the soil during the day and reduce longwave radiative cooling at night by reducing the seedlings' view of the cold night sky. Trenches may not be as effective in deep frost pockets where the warming effect of the trench is overwhelmed by the cold air which flows into the trench. Trenching may also improve soil moisture availability.

Removing vegetation and surface organic cover with patch or continuous scalping treatments (such as with patch scarifier or disc trencher) can reduce the frost hazard on some grass-covered sites. The small scalps created with a planting shovel are usually not adequate to reduce the frost hazard for a sufficient length of time to establish seedlings. Large-sized scalps created with a cat blade may be effective for frost reduction, but can also have detrimental effects on soil nutrient and physical properties.

In cold, wet areas, mineral soil mounds that raise the seedling out of the cold air layer near the ground surface can be an effective method of improving seedling growth and survival. Mounds also promote soil drainage and enhance soil warming. However, mounding may increase frost damage by causing seedlings to flush earlier.

4.2 Species and Stock Type Selection

Douglas-fir, western hemlock, and western redcedar have the lowest tolerance to summer frost among native tree species in the Cariboo Forest Region. They are easily regenerated on Very Low and Low frost hazard sites, provided moisture and other requirements are met. However, they are often damaged by frost on Medium hazard class sites. Their regeneration success is very poor on High hazard class sites.

Interior spruce plantations seldom suffer significant frost damage on Low and Medium frost hazard class sites, but on High hazard class sites, they do experience considerable frost damage in some years.

Lodgepole pine should probably be planted in the lower-lying areas on High hazard sites because of its higher frost tolerance. Subalpine fir may experience less frost-related mortality than spruce on High hazard sites. Very High hazard class sites have an unacceptable risk of frost damage for interior spruce; lodgepole pine, black spruce, or whitebark pine are the only native species that will likely survive frost on these sites. Even lodgepole pine will suffer damage and mortality on these sites in some years.

Stocktype selection has shown some promise for improving regeneration success on frost-prone sites. Cold-stored stock planted in the spring on high elevation or other frost-prone sites is often very susceptible to frost damage in the spring and the fall. Summer-planted stock which has already set bud (and is therefore more frost hardy) offers one means to reduce frost damage.

There is some evidence that seedlings are more susceptible to frost in the first year after planting than in the subsequent years when they have had time to synchronize physiologically with their environment. Older seedlings are also usually larger and better able to recover from frost damage than are young seedlings.

4.3 Harvest Methods

Clearcut sites are generally more prone to summer frost than are partially cut sites. In partial cutting systems, the residual canopy reduces the rate of radiative cooling and reduces the risk of seedling frost damage. A residual canopy cover of at least 50% is generally required to reduce the frost hazard class significantly.

Cutblock boundaries and leave-strips can be located to reduce frost hazards on some cutblocks. Openings created in the timber on the downslope side of a clearcut can decrease frost hazard near the timber boundary by allowing cold air to flow out of the lowest areas of the block. Leave-strips can be located and oriented to minimize obstruction to cold air flow.

4.4 Nurse Crops

Lodgepole pine or deciduous species can be established as a nurse crop to protect regeneration of more frost-sensitive species such as Douglas-fir and interior spruce. Deciduous tree nurse crops are used to protect conifer seedlings from summer frost damage in Scandinavian countries. After the coniferous trees are established, the deciduous canopy is removed to accelerate the growth of the conifers. In the Cariboo Region, a Douglas-fir plantation beneath an existing 4 m tall lodgepole pine canopy suffered little apparent frost damage, while that on an adjacent clearcut site without a pine canopy suffered extensive mortality because of frost.[2] The nurse-crop role of lodgepole pine occurs naturally in many subzones of the Cariboo Forest Region.

Another option is to create a mixed-species plantation of lodgepole pine with either interior spruce or Douglas-fir (approximately 800 pine and 600 fir or spruce per hectare). Frost damage and mortality of the spruce and Douglas-fir may occur in the first few years. However, after the more rapidly growing lodgepole pine becomes well established, the interior spruce and Douglas-fir will benefit from the frost protection provided by the pine canopy. Additional natural infilling of spruce or Douglas-fir will often occur.

4.5 Microsite Selection

Planting in certain microsites can reduce frost damage to seedlings. Raised mineral soil areas near logs and stumps or areas beneath tall shrubs or small residual trees can reduce the frost hazard. Microsites that trap cold air, such as shallow depressions on the uphill side of logs that lie horizontally across the site, can increase the microsite frost hazard.

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[2] Sutherland, D.C. pers. comm. Forest Sciences Officer, B.C. Ministry of Forests, Cariboo Forest Region, Williams Lake, B.C. 1989.

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APPENDIX 1: Atmospheric Environment Service frost frequency data[3] for biogeoclimatic units in the Cariboo Forest Region

Mean number of days of frost in each temperature class.

BGC Unit	May		June		July		August		September	
	0 to -3 °C	-4 to- 10 °C	0 to -3 °C	-4 to- 10 °C	0 to -3 °C	-4 to- 10 °C	0 to -3 °C	-4 to- 10 °C	0 to -3 °C	-4 to- 10 °C
BGxh3	10	1	1	0	<1	0	<1	0	5	1
PPxh2	no data									
SBSmh	6	1	1	0	<1	0	<1	<1	3	<1
IDFxm (East)	6	<1	1	0	0	0	<1	<1	3	1
IDFmw2	no data									
ICHmk3	9	2	2	0	<1	0	1	0	3	1
ICHwk2	9	1	2	0	0	0	0	0	3	1
SBSdw1	9	2	2	<1	<1	0	1	<1	6	2
ICHvk4	no data									
ICHdk	no data									
ICHmw3	no data									
IDFdk3	9	2	2	<1	1	0	1	<1	6	2
SBSdw2	6	1	1	0	<1	0	<1	0	3	2
IDFxm (West)	no data									
IDFdk1	no data									
IDFdk4	11	4	5	<1	1	0	2	<1	10	1
SBSmc1	no data									
SBSmc2	no data									
MSdk	no data									
SBPSmk	no data									
SBPSmc	no data									
SBPSdc	18	5	10	1	4	<1	7	1	14	4
ESSFwk1	13	3	4	<1	1	0	1	<1	8	2
SBPSxc	5	13	9	3	5	<1	10	1	6	11
SBSwk1	no data									
ESSFdc2	no data									
MSxv	no data									
ESSFxv	no data									

Note that these are air temperature data measured in a Stevenson screen at the 1.2 m height, and that both the frost frequency and severity can be much greater at the height at which seedlings grow. Sites chosen by the Atmospheric Environment Service are not necessarily located in landscape positions representative of typical cutblocks.

Biogeoclimatic units indicated as having "no data" have no long-term recording stations within the Cariboo Forest Region. For some, data may be available from areas outside the Cariboo Region.

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[3] These data were provided as a special request report by Atmospheric Environment Service, Vancouver, B.C. They are unpublished summaries of minimum temperature data from AES weather stations

APPENDIX 2: Frost damage symptoms in conifer seedlings

The frost tolerance of conifer seedlings varies throughout the year. During the winter when seedlings are in a hardened condition, they are able to withstand temperatures below -20°C. However, during the growing season they can be susceptible to damage at temperatures of only a few degrees below freezing. Low temperatures, rapid tissue cooling, long exposure to low temperatures, and a high frequency of frosts during the growing season all increase the degree of frost damage to seedlings.

Seedling frost damage usually occurs on the current year's foliage, particularly on the terminal and on upper laterals that are directly exposed to the cold night sky. Damage often occurs soon after the buds burst in the late spring when the probability of damaging frosts is very high. Seedlings are also vulnerable to damage before they have hardened off in the late summer, when the probability of frosts begins to increase again.

Frost damage symptoms are easily identified in the first year after damage. They usually begin to appear within a few days after a frost occurs and are often fully developed within 1–2 weeks. Browning, stem curling, and necrosis of foliage or active growing points are common symptoms of frost damage. Either partial or total needle damage can occur. Sometimes only the outer exposed portions of the needles and the terminal shoot tip are damaged. Usually, whole shoots are affected. Damaged needles can remain on the seedling for many weeks before abscission occurs. Dead, defoliated shoots often remain attached to seedlings for a number of seasons after the frost damage occurs.

Damage to the terminal shoot usually redirects growth toward the lateral shoots. As a result, older seedlings develop a bushy growth form with multiple leaders if they are repeatedly frost-damaged over the years. The crowns of older seedlings often appear rounded and the foliage becomes denser, similar in appearance to damage caused by animal browsing. Sometimes these seedlings are able to grow vigorous shoots in less frosty growing seasons and are able to grow out of the cold air layer near the ground surface.

Sublethal frost damage can occur without the seedling exhibiting visible symptoms. Sublethal damages to cell membranes, organelles, xylem elements and root tissue have been found to affect seedling photosynthesis and transpiration significantly. As a result, the growth and vigour of frost-damaged seedlings are usually much reduced. Seedlings may also become more susceptible to other environmental stresses after frost damage has weakened them. For example, frost can cause tissue damage, which ultimately results in insufficient carbohydrate production and severe water stress.

APPENDIX 3: Synonomy of codes for biogeoclimatic units in the Cariboo Forest Region

New correlated code (This guide)	Previous code
BGxh3	BGg
BGxw2	BGe
CWHds1	CWHc
ESSFdc2	ESSFe1
ESSFxv	ESSFg
ESSFwc3	ESSFh2
ESSFwk1	ESSFh1
ICHdk	ICHe3
ICHmk3	ICHe2
ICHmw3	ICHm1
ICHwk2	ICHh1
ICHwk4	ICHh2
IDFdk1	IDFb1
IDFdk3	IDFb2
IDFdk4	IDFb5
IDFmw2	IDFj1
IDFxm	IDFe4
IDFxw	IDFe2
MSxk	MSc
MSxv	MSd
PPxh2	PPd
SBPSdc	SBSa3
SBPSmc	SBSa2
SBPSmk	SBSb
SBPSxc	SBSa1
SBSdw1	SBSk1
SBSdw2	SBSk2
SBSmc1	SBSm2
SBSmc2	SBSe1
SBSmh	SBSl
SBSmw	SBSc
SBSwk1	SBSj1